Two proton decay in ^{17}Ne

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There has been considerable interest lately in the study of nuclei near and beyond the proton drip line. Much of the information about this region has been obtained through the study of the decay of nuclei near the proton drip line through the emission of protons. In certain cases, nuclei are actually unbound with respect to decay by emission of two protons. One particularly interesting case is that of 17Ne. Here, one encounters the rare situation where the separation energy for two-proton emission is actually less than that for one-proton decay. In fact, the ground state of the intervening nucleus 16F is unbound with respect to proton decay. The first excited state of 17Ne lies at 1.258 MeV, below the 1-proton separation energy, but above that for 2-proton decay. Here then lies the opportunity to observe the two-particle decay of the state which cannot proceed through a discreet intermediate state in 16F. This is a particularly interesting possibility in this case, as the two-proton system is not long-lived. Here, if the decay is to proceed sequentially, as favored by phase-space arguments, the "intermediate states" must be in a negative-energy continuum, or perhaps the tail of the 16F ground state resonance. Otherwise, the two protons will be in a short-lived correlated state.

To date, 17Ne has been studied only as the product of intermediate fragmentation reactions. This method has a number of disadvantages. The nucleus is produced at a high velocity, and the excited state must be populated through Coulomb excitation or some other mechanism which I don't know right now. The protons are tightly correlated at very small angles and the correlations between them are difficult to disentangle. The situation can be improved if 17Ne could be produced as the product of a light-heavy ion reaction. With the stable beams currently available this is not possible. With the availability of intense beams of radioactive ions, however, there exist new possibilities for studying 17Ne. On promising reaction is 12C(9C,alpha)17Ne. This reaction is expected to have large cross sections, perhaps near 1mb/sr. At modest beam energies near a few MeV/nucleon the kinematics of this near symmetric are particularly adventageous for correlation studies. This reaction also posesses a rather large, positive Q value which is helpful for detection. The intensities of the 9C beams expected from the fragmentation based facility are on the order of 10**9 particles/sec. The emitted alpha particles are in an energy range particularly well suited to detection with silicon detectors. In addition, the protons emitted by the residual 17Ne nucleus have energies of only a few MeV, and can be stopped in 500 microns of silicon. With a large solid angle detector subtending approximately 1 sr, alpha-particle rates of ~100 counts per second per state can be anticipated. The proton detection efficiencies will be large, and with a detector system possessing reasonable angular resolution and multiple hit capabilities detailed study of the angular and momentum correlations between the decay protons should distinguish between direct and sequential pathways. One very large advantage is that the full kinematics of the situation may be reconstructed without the neccesity of detecting the heavy 15O remnant, as the vector momentum of the primary 17Ne product is already determined from the detected alpha particle.

Some detailed information:

Anticipated beam intensity at 60 MeV: I(9C)~ 1 * 10**9 pps
Target thickness: 100 micro-gram/cm2
Assumed cross section: 1 mb/sr
Detector solid angle: 1 sr
Jacobean factor: ~2.0
Expected alpha rate/state in 17Ne: ~10/sec
p-p-15O opening angle: <=40 degrees
if E(17Ne) = 10 MeV (theta(alpha)~30 degrees)
<=20 degrees if E(17Ne) = 30 MeV (theta(alpha)~70 degrees)
Estimated alpha-p-p efficiency: ~10%
Expected alpha-p-p coincidence rate: 1/sec/state

Study of ^{20}Mg

The nucleus 20Mg is quite interesting from a number of different standpoints. It lies very close to the proton drip line, and posseses, in the standard shell model, a closed N=8 neutron shell. In addition, it has the rare property, shared with 17Ne, that its 2-proton separation energy is actually smaller than that for one proton. Finally, this nucleus has been studied in the context of the isobaric mass multiplet (IMM) equation for A=20. This nucleus presents the opportunity to study exotic ascpects of nuclear structure and decay, as well as test the predictions of the rearrangement of shell structure far from the valley of stability. The one, and two proton separation enegies are 2.650, and 2.329 MeV, respectively. Should 20Mg possess and excited state between excitation energies of 2.329 and 2.650 MeV, it would also have the interesting possibility of decay by two proton emission without an intervening discreet level in the intermediate nucleus 19Na, which itself is proton unbound in its ground state. Calculations from a microscopic three-cluster model by Descouvement predict several 0, 2 and 4+ states at excitation energies below 5 MeV, with the precise positions depending on the exact form of the interaction. Other calculations which presume 4-proton correlations suggest a possible 4-proton "halo" or "skin" for 20Mg, although these results are the subject of some controversy. Despite these interesting properties, in fact very little is known about 20Mg, beyond its mass, its charge and matter radii, and maybe a couple of other things. No excited states are known. This dearth of information stems from the difficulty of producing 20Mg. Currently, 20Mg has only been produced as the product of high-energy fragmentation reactions and studied only in its ground state. Due to its position far from the valley of stability it is virtually inaccessible to "standard" nuclear reactions involving stable beams and targets. This situation may change with the availability of radioactive ion beams. Even with intense beams of unstable ions 20Mg poses a challenge. A number of reactions are still possible, the most promising of which is likely to be 12C(18Ne,10Be)20Mg. This reaction has the advantages of near-symmetric kinematics, and a reasonably light ejectile which could be detected with good resolution in an E-Delta E position-sensitive telescope. It is important that the DE measurement have sufficient resolution to separate 10Be from 9Be which we expect to be significantly more prolific. Despite the rather negative Q value of -24.8 MeV, simple Q-matching arguments suggest that the cross section for this reaction may not be too small, perhaps as large as 10 micro-barns/sr. Other possible reactions are

12C(14O,6He), 16O(10C,6He), 16O(13O,9Be) or 16O(14O,10Be). All possess similar Q values, and rely upon beams that we expect to obtain with intensities of a few*10**8 pps or greater. Initial exploratory exploratory experiments would be simple, aimed at studying the low-lying level structure of 20Mg. Subsequent to that, more ambitous measurements would be undertaken to search for the possible two-proton decays of excited levels in 20Mg, and compare these results to those that may be obtained from 17Ne. Some details follow: All rates assume a 1sr detector, target thickness of 100 microgram/cm2, and an admittedly fanciful 10 microbarn/sr cross section per state.

Reaction	Q value	Beam intensity	Rate (cnts/min/state)
12C(18ne,10Be)20Mg	-24.870	6*10**9	36
12C(14O,6He)20Mg	-27.158	9*10**9	54
16O(10C,6He)20Mg	-24.203	1*10**10	60
16O(13O,9Be)20Mg	-10.544	6*10**8	4
16O(14O,10Be)20Mg	-26.907	9*10**9	54